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Fisheries Development Division Fisheries and Habitat Management

**Newfoundland
Region**

**AN EXPERIMENT IN FIBREGLOSSING
A WOODEN INSHORE FISHING VESSEL**

PROJECT REPORT FDD 1987/88-130

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An Experiment in Fibreglassing
A Wooden Inshore Fishing Vessel

1987

By: Joseph S. Dominic

Project Report FDD - 87/88 - 130

Fisheries Development Division
Fisheries and Habitat Management
Department of Fisheries and Oceans
Newfoundland Region
P.O. Box 5667
ST. John's, Newfoundland
A1C 5X1

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ABSTRACT

Dominic, J.S. 1987. A Study of the Effects of Fibreglassing a Wooden Inshore Fishing Vessel. Project Report FDD - 87/88 - 130.

The hull and deck of a 30 year old, 18.2m (60 ft.) crab fishing vessel were fibreglassed in March, 1985 and a new wheelhouse, also covered in fibreglass, was added in October. After two seasons of fishing, the vessel was put on dock in the Marine Service Center at Harbour Grace, Newfoundland, where the condition of both the wood and fibreglass sheathing was examined. These investigations resulted in recommendations for vessel preparation and testing prior to fibreglassing and for subsequent maintenance procedures.

PREFACE

This study was carried out by Joseph S. Dominic, Fisheries Assistance Division, on behalf of the Fisheries Development Division, Fisheries and Habitat Management.

A grant was provided to George Roche, Coley's Point, owner of the **M/V WAVE**, who contracted Neldo Marine, Argentina, to fibreglass his vessel.

Scientific Authority:

Gerald Brothers
Technical Development Officer
Fisheries Development Division
Fisheries & Habitat Management Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland
A1C 5X1

INTRODUCTION

If the effective working life of a fishing vessel can be safely and economically extended by fibreglassing, the value of this low cost alternative to vessel replacement could be immense.

The **M/V WAVE** was built in Shelburne, Nova Scotia, in 1957 by Hartley Cox to an overall length of 18.2m (60 ft.) and beam of 5.3m (17 ft. 6 in.). In 1976 the vessel was purchased from Gordon Corkum of Nova Scotia by her present owner, George Roche of Coley's Point, Conception Bay, Newfoundland.

George Roche used the **M/V WAVE** primarily for crab fishing but also fished a seine for various pelagic species.

The vessel is of conventional carvel (plank on frame) construction, sheathed in 42mm (1 5/8") plank. Mr. Roche refastened the planking in 1981. Other than annual maintenance, no other major work was performed by him prior to the fibreglassing.

MATERIALS & METHODS

HULL PREPARATION

Work on fibreglassing the **M/V WAVE** began on February 26, 1985 at the Marine Centre in Harbour Grace. Because of the noxious vapours present during fibreglassing, and the busy schedule at the Marine Centre it was decided the work would be done under temporary shelter outside. An oil-fired hot-air furnace was installed to heat the shelter to a minimum

temperature of 15.6°C (60°F) providing enough ambient heat to allow normal curing of the resins. The vessel was parked and heeled over on her starboard bilge, a wood frame draped with plastic and tarpaulins was secured to her port rail and the heating system was installed.

Initial work involved preparing the hull for fibreglassing. All through-hull fixtures and the sterngear were removed and the hull ground to bare wood. During the paint removal process considerable water was found at the paint/plank interface, indicating possible saturated planking. Holes were bored at low points near the keel to drain the bilge. All ice and free water had to be drained from the hull and the plank surface let dry to prevent dampness interfering with curing the layers of fibreglass. To counteract the tendency of stiff woven roving to pull away from and round off square edges, a new keel shoe with radial (rounded) edges was installed. Any voids, or pockets, formed at raised plank edges or tight inside corners (e.g. where the garboard butts the keel) would be weaker than areas where the glass has full contact with solid wood. These would also form reservoirs where water could accumulate and cause damage due to freezing.

A polyester-based filler was used to form rounded fillets to lessen unbroken contact at these inside corners.

Finally, badly damaged or rotten planks were replaced and all large seams were filled.

APPLICATION OF FIBREGLASS SKIN

After several days in the heated enclosure, the exposed plank surface had dried sufficiently to allow the application of fibreglass. The first ply consisted of two layers of 1.5 oz. mat set in resin (Fibreglass Canada's wax-free high exotherm (fast curing) Vibrin #1029) with a 60 percent solution of MEK (Methyl Ethyl Keytone Peroxide) used as a catalyst. The purpose of two mat layers back to back was to provide optimum bonding between the fibreglass and the wood. (Because of the density and compactness of the fibres, mat provides the maximum degree of waterproofing possible with conventional fibreglass fabrics. The coarser roving, with large voids in the weave of the material, does not adhere well when applied directly to the plank and provides the lowest level of waterproofing.

Double mats will reduce the likelihood of damage caused by water inside the hull seeping out between and through the planks. This would result in weakened interlaminar bonds and possible further damage from freezing.

Mat, on the other hand, also provides optimum bonding between layers of roving.

The main body of the laminate was to be composed of four additional plies of alternating layers of 24 oz. woven roving and 1.5 oz. mat. During this portion of the layup, Vibrin #1027 Polyester Resin was used. This is a wax-free, low exothorm (slow curing) resin. An unfinished job (surface), if kept cool and out of direct sunlight or heat, may be left for over a week without total loss of the structural integrity of primary bonding. The catalyst used was again 60% M.E.K.

Due to the very cold February temperatures and the frozen ground on which the M/V WAVE was parked, the hot air furnace could not maintain constant temperatures throughout the depth of the enclosure. At the keel, approximately 25 cm (10") above the ground, the temperature was around 10°C (50°F), whereas at the rail the temperature was over 21°C (70°F). To reduce the effects of the temperature gradient, the catalyst concentration was increased to four ounces per gallon below the turn of the bilge from the 1.5 to two ounces used above the bilge. This resulted in a more uniform gel time which allowed work to continue smoothly.

The fibreglass layers were applied alternately from forward to aft and aft to forward, with the length (warp) of the roving running from gunwale to keel. An average of four inches was provided between each layer to allow proper overlapping. Good practice dictates a minimum of four inch overlaps to maintain adequate and consistent shear strength between the layers. Each layer was carried right around the keel to the opposite garboard so that when both sides of the hull were finished a double thickness of fibreglass encased the entire keel. This ensures that both sides of the hull are effectively tied together, and provides greater strength at heavy load points (i.e. when the vessel is out of water on keel blocks).

After the first two plies of roving/mat (5mm thickness) were applied, and had hardened, it was screwed to the hull. A plywood template was used to guide the drilling of approximately 10,000 holes into which were driven stainless steel screws (1.5" #10 flat head). The screw holes were countersunk to allow the flush setting of the heads with the fibreglass.

Following the installation of the screws, the final layers of glass were applied, consisting of two more paired layers mat/roving topped with a surface (skin-out) ply of two layers of 1.5 oz. mat. Onto this was applied a finish coat of pigmented resin.

After the port side of the vessel was completed she was heeled over to expose the starboard side. The shelter was adjusted and glassing continued as before.

The laminate on both sides of the hull was run out onto the bulwarks approximately 20 cm (8") above the deck line. The scuppers were glassed right through to the inside wall of the cased-in bulwark.

An extra ply of mat/roving was applied below the crab pot hauler on the hull side to reinforce this area against abrasion and wear caused by the pots as they bump and scrap their way to the deck.

After the hull sides and stern had been glassed, fastened and finished, the **M/V WAVE** was righted and the shelter erected to cover the deck. All deck fixtures and equipment not to be fibre glassed over were removed. Again the plank surfaces, including the fish hold hatch coaming, were ground free of paint and let dry.

The first ply was composed of two layers of 1.5 oz. mat, again to provide a water barrier and the best interface for bonding the following main plys to the underlying wood. This ply was carried from the deckside at the bulwark to the inside face of the fish hold hatch coaming down to about deck level, effectively encasing the coaming. The following ply was 1.5 oz mat and 24 oz. roving, which was also carried up around and into the coaming. As with the hull, the template and 1.5 inch #10 stainless steel

flathead screws, countersunk for smoothness, were used to mechanically fasten the fibreglass to the vessel.

Fibreglassing continued the same as on the hull, with the two final mat layers being carried up the inside face of the bulwark to about 30 cm (12 in.) above the deck. The surface finish on the deck was a hand applied, non-skid white thixotropic resin.

By the time this work was completed (in mid-April) the crab fishing season was open and the vessel was put into the fishery. In October, a new wheelhouse was constructed and sheathed in fibreglass.

REMOVAL OF SAMPLES

In November 1986, the **M/V WAVE** was put on dock. Four cylindrical plugs were cut from separate locations in the hull and deck in order to examine the condition of the fibreglass sheathing, the underlying wood and the bonding between the two.

Immediately upon removal, the moisture content of each plug was measured. Readings were taken using a Lignomat H-60 meter. Levels were checked on both end surfaces as well as on the perimeter along its length in 6 mm increments. This particular moisture content meter is graduated to read M.C. to 60 percent in construction grade timber. However, the fibre saturation point for typical timber is about 30% M.C. Readings indicating over 30 percent cannot, in most cases, be considered valid. This is because the current from the meter (which measures the electrical resistance of the wood) no longer passes across the surface of the cell walls, but rather short-circuits "through" the saturated cells. This results in a much lower

resistance to the current and an unreliable and artificially high M.C. reading.

All core samples were taken from the port side hull with the exception of one removed from the deck over the lazarette on the port quarter. The deck plug was 30 mm (1 3/16") in diameter. All others were 42 mm (1 5/8") in diameter.

The first plug was removed from the engine room area at a depth of 15 cm below the waterline and just forward of the wing tank. The plank measured 42 mm (1 5/8") in thickness. A dark liquid oozed from the wood during cutting. The plug had a dark discoloration and appeared sound but very wet. There was an unpleasant smell present during and after boring. This was not due to cutting through the fibreglass sheathing. The GRP disc removed with the plug was not bonded to the wood. Immediately upon removal, M.C. readings were taken in 6mm increments along the length of the plug and on both faces. All readings indicated greater than 60 percent M.C. Careful examination of the inner surface of the GRP disc revealed no wood fibres embedded in the resin surface. The thickness of the disc varied from 8.0 mm. to 8.7 mm around the perimeter. The wood portion of the plug was weighed at a local pharmacy minutes after removal. Its weight was 33 g.

The second plug was removed above the head through-hull discharge in the foc'sle. The wood here was very wet and sounded 'spongy' when tapped with a light hammer. During removal of this plug a dark, pungent liquid oozed out around the cutter. The liquid appeared to be mainly water. This sample was quite wet but appeared sound with the exception of the inboard

surface. Fibres lifted from it broke short, indicating that the wood had deteriorated somewhat. A boxed-in section around the discharge pipe had to be removed to gain access to this area. The entire foc'sle was sheathed with panneling from the cabin sole to the deck. No provision for ventilation was evident. The plank sample was dark and discolored and measured 42 mm (1 5/8") in thickness. All M.C. readings were over 60 percent. The GRP disc thickness varied between 7.5 mm and 8.5 mm around its perimeter; the disc was not adhering to the plank.

The third plug was taken from behind the ceiling in the fish hold, just aft of the engine room bulkhead, approximately half way between the waterline and the deck. The ceiling in the hold on both sides was flush to the deck with no provision made for ventilating the space between it and the hull planking. After piercing the fibreglass skin of the hull, an estimated two to three cc of dark, unpleasant smelling, watery liquid ran from the cut onto the saw and down the hull side. The wood appeared sound and again the fibreglass was not adhering. Moisture content meter readings were in excess of 60 percent. The wood sample was 42 mm (1 5/8") thick. The fibreglass thickness was similar to the previous two discs, averaging 8mm.

The fourth plug was removed from the lazarette deck. No liquid appeared during this process; however, the now familiar smell was present. The wood itself was quite sound but dark and discoloured. All M.C. readings were greater than 60 percent. The thickness of the deck plank was 44.5 mm (1 3/4"). The fibreglass was not adhering to the plank and measured 8mm (5/16") in thickness.

All of the fibreglass samples removed with the wood plugs were in excellent condition. There was no evidence of poor bonding between the fibreglass layers.

All plugs, after removal and preliminary examination, were stored in sealed poly bags for further analysis. The plug holes were then filled with a thickened Chem Tech T-88 structural epoxy mixture and surfaced with Chem Tech F-9 epoxy surfacing compound. Pigmented resin was applied to match the hull.

CONDITION OF THE FIBREGLASS SKIN

The deck and hull topsides were first inspected. All laps were sound and even though this vessel had been frequently used to break channels through the frozen harbour there was little sign of wear on the stem.

Some abrasion damage was found on the starboard side below the crab pot hauler. This area had been given extra layers of fibreglass to allow for wear. The damage was not severe. Several feet forward of this an area about 15 cm (6") square had been damaged by a protruding bolt on the owner's wharf. Vessel motion had caused the bolt to rub about half way through the fibreglass over this area. Impact damage evident throughout the area was slight, but some delamination had occurred. Repairs were effected by grinding away the outer plys of fibreglass over the damaged area and for several inches outside the area. The resulting shallow cavity was filled with F-9 Epoxy Surfacing Compound and contoured and finished to match the hull. Next, the entire underwater hull surface was inspected visually. Much of the fibreglass was found to be in loose contact with the hull, particularly in the aft section near the keel and deadwoods.

The fibreglass covering the deck was sound and all main overlaps were intact. Most of the plys ended at, or, a short way up the bulwark. However, the top two layers of mat that had been carried up the bulwark to about 30 cm. (12") above the deck had released from the bulwark along approximately one half its total perimeter. In some places the failure of the bond extended right down to the deck. (The original bulwark was enclosed with wood sheathing; the resulting enclosed space was not ventilated).

The fibreglass encasing the fish hold hatch coaming was in the worst condition. It did not appear to have been mechanically fastened to the wood, as large pockets could be detected all around. The fibreglass and the wood were, for the most part, not in contact. The top edges of the coaming had been damaged by constant contact with crab pots and in places the fibreglass had been worn completely through exposing the wood. This provided an excellent location for water to enter and lodge in the air pockets behind the fibreglass, where it would likely also seep underneath the fibreglass deck covering. Freezing will compound this problem even further.

INCLINING EXPERIMENT

An inclining experiment was conducted to try and determine what effect the addition of the fibreglass had on the stability of the **M/V WAVE**. Before this was done, the vessel's lines were lifted and other stability-related information determined so that the pre-fibreglassing stability characteristics of the vessel could be calculated.

To conduct the inclining experiment the fuel tanks were filled and pressed up to the top of the fill pipes. Four oil drums were filled with water, weighed on electronic scales, identified and hoisted aboard the vessel to serve as inclining weights. A line was suspended from the end of the raised boom and to it was fastened to a plumb bob which hung submerged, just inches above the bottom of a water-filled fish box on the centerline in the fish hold. Across the top edge of the box was placed a level with a metric scale on one side so that the deflection of this pendulum could be recorded after each transverse move of the deck weights.

Prior to loading the weights aboard, draft marks were taken at the stem head, midships, and on the centerline at the transom. The vessel was then checked for list and found to be floating on an even keel.

The vessel was untied from the wharf and a single 3/4" rope attached to a ring bolt on her starboard transom. She was let swing freely on this tether.

A centerline was drawn on deck and the position (distance from centerline to center of the weight) and mass of each weight recorded. A rule (attached to the level described above) was positioned close to the plumbline at a point from which deflection would be measured. The distance from the suspension point of the plumb bob to the edge of the level (where deflection measurements were made) was recorded as the "pendulum length".

Before each shift of a water-filled barrel, the vessel was pulled into the wharf and let drift freely during which time readings of the resulting deflection were taken. The first shift was barrel #1 from the starboard side to port. The position of the barrel was recorded as well as the

deflection of the pendulum resulting from the induced list. The second move was barrel #2 from starboard to port. Next, all four barrels on the port side were moved, one by one, to starboard. Finally, barrels 3 and 4 were singly moved back to their original positions on the port deck. In all, eight shifts were made, in each case the total transverse distance of each barrel moved, and the resulting pendulum deflection recorded.

However, by the time the third shift was made enough wind and wave action had developed to induce a minor hull reaction. The wind was strong enough to cause a slight bow in the plumb line. Both factors affected the readability and accuracy of the following five readings. Due to the forced approximation of several of the readings and thus the likely introduction of error, a reduced confidence is placed in the calculation of the center of gravity.

RESULTS AND OBSERVATIONS

WOOD SAMPLE ANALYSIS

A sample of the hull planking was sent to Forintek Canada Corp. for analysis. The plug was subjected to chemical testing, both light and scanning electron microscopy, and a culture was prepared and incubated.

The testing revealed a large amount of iron present in the sample, presumably accumulating over the years from rusted fastenings. The preservative PCP (pentachlorephenol) was present, and a high amount of chlorine. Sodium levels were low, so it is unlikely therefore that the chlorine originated from sea water, but rather as a product of the PCP.

No deterioration of the wood could be visibly detected using either of the two methods of microscopy. There was no visible sign of rot producing fungi in the sample.

A culture was prepared and incubated for four days. After this period, analysis indicated no bacteria or fungi were present. We believe this was due to the presence of the preservative.

The wood was identified as white pine.

Plug #1 removed from the vessel was weighed minutes after removal. Because of the limitations of the lignomat meter in measuring M.C. above 30 percent, it was felt necessary to use another method to calculate initial moisture content. The plug was allowed to dry and was re-weighed after stabilizing (64 days at 20 degrees C.). The initial weight of the sample was 33 g. and the final dry weight was 20 g. Assuming the moisture content of the dried sample to be 10 percent, this indicates an initial M.C. of 83% by weight.

A subsequent conversation with Dr. Seifert and Dr. J.P. Hosli of Forintek revealed that white pine could contain up to 200% water by weight. (70% by volume).

All that can be said with certainty about the moisture content of the wood is that it was soaked beyond the fibre saturation point (greater than 30 percent) when it was tested. One limitation of the meter when measuring M.C. on saturated wood has already been noted; the presence of PCP, chlorine and iron in the sample likely introduced additional error. The method of comparing the wet and dry weights of the sample is also not totally accurate because of the presence of the PCP and an oil-based

carrier. These chemicals are present in the sample, and have weight. They also affect the water retention qualities of the wood, and unless the concentration is accurately known, the net effect of their presence on any moisture calculation is unknown.

Due to the presence of PCP it is unlikely that in this vessel there would be any problem due to rotting. Forintek did indicate that if, in a similar vessel no preservative was present and the vessel were dried out enough, the presence of large amounts of iron could actually promote the growth of rot-producing fungi (by providing extra mineral nutrients).

GRP BURNOUT TEST

A burnout test was performed on two of the three fibreglass discs removed with the hull plugs. Prior to conducting the tests, the inner and outer double layer of mat were removed by grinding. These plys are normally richer in resin than the body of the laminate. Left in place for the test, these resin-rich layers would result in an incorrect measurement of glass content in the main body of the laminate.

The discs removed with plugs 1 and 2 were used for this test. The plugs were weighed on three different electronic torsion balance scales prior to the test, as were the poly bags used to contain the residues for re-weighing afterwards.

The results of the test on both plugs revealed glass fibre content to be virtually identical. Plug 1 contained 45.56% glass, and Plug 2, 45.01%. This indicates a laminate quality of the highest order, normally achieved by vacuum or pressure molding techniques or the best hand layup under ideal conditions.

Glass content much beyond 45 percent is indicative of a condition known as "resin starvation". When this occurs too little resin is present to provide maximum interlaminar bonding. The resulting laminate has very poor impact and abrasion resistance and inferior overall strength. Likewise, a laminate containing less than 30 percent glass is also unacceptable.

If, based on these two samples, an assumption can be made that similar homogeneity exists throughout the hull, the quality of the entire skin is much better than was initially expected.

Although the laminate averaged only about 5/16" in thickness, the glass content is sufficient for a single skin (fibreglass only) vessel of this size, provided a grid of "suitable framing" was installed at 18" centers (460 mm). Should the existing wooden hull deteriorate sufficiently, the fibreglass now in place would be incapable of supporting staff.

STABILITY

Another critical question that arises when one considers fibreglassing a wooden boat is - what effect will it have on the vessel's stability? In the case of the M/V WAVE two factors made it impossible to secure an absolutely conclusive answer to the question.

In the first place, no stability test had been done on the vessel prior to fibreglassing. This precluded any comparison in the shift of center of gravity, or determination of the effects of absorbed water. A variety of accurate measurements had to be taken so that hull lines could be reproduced and the vessel's pre-fibreglassing displacement and other stability-related information mathematically calculated.

Secondly, a controlled inclining experiment designed to determine the centre of gravity and the stability of the M/V WAVE after fibreglassing was partially invalidated by adverse weather conditions. Eight separate inclining tests were conducted in the experiment using accurately weighed water-filled oil barrels for inclining weights. Standard techniques were employed to measure the various angles of heel caused by each subsequent placement of the weights on the vessel.

Unfortunately, only the first three tests were conducted under ideal conditions. A rising wind and the resultant wave action affected both the accuracy and the readability of the measurements taken in the other five tests.

An additional problem in determining the net change made in the stability of the vessel by adding the fibreglass lay in not knowing the effect of absorbed water on the vessel - water either lost through evaporation or further absorbed in the wood because of poor ventilation and the overall sealing of the outside hull.

In spite of these problems, the project team placed sufficient confidence in the calculation of pre- and post-fibreglassing stability characteristics to conclude that the addition of the fibreglass (and its metal screw fastenings) did add slightly to the stability of the M/V WAVE. Even though fully reliable and accurate measurements may not have been made, the vessel's centre of gravity was effectively lowered. She also benefited from the slightly increased beam at the waterline.

The "as fibreglassed" center of gravity (KG) was found to be 2.418 m above the hydrostatic baseline (Table 2). However, after the glass and

fastenings were mathematically removed (Table 5), it was found that the KG before fibreglassing (all other things being constant) was 8 mm higher. Although the center of gravity was lowered only slightly by the addition of the glass, it did somewhat improve stability.

At this point, caution is suggested in the drawing of conclusions based on this one sample. it is doubtful that the stability of vessels in general will be improved by sheathing them with fibreglass. Further testing on a broader range of vessels is required to determine that.

When compared to the Canadian Coast Guard stability standard (Stab. 4A) the Wave met all but one condition, that being the greatest GZ (righting lever) must occur at an angle of heel greater than 25 degrees. In this case the largest GZ occurred at 20 degrees (Table 3).

To correct this deficiency a ballast calculation was performed. It was found that the addition of 2.50 tonnes of permanent ballast 2.00 meters below the present center of gravity would be sufficient. This would locate the center of mass of the ballast 0.42 meters above the baseline at midships (Table 4).

Not only was the minimum angle requirement for maximum GZ exceeded but the "range" of stability was now extended from 62.10 degrees to 74.29 degrees (Figure 4). The area bounded by the new GZ curve (ballasted condition) is significantly larger and higher values of GZ occur. This results in greatly enhanced stability throughout the entire range and an overall general improvement.

The M/V WAVE has a relatively flat bottom and very shallow draft. Her center of gravity is considerably higher than that normally found in a typical deep-draft boat of the same length and beam.

CONCLUSIONS

Although we were satisfied that fibreglassing the M/V WAVE improved her stability, this was not demonstrated conclusively.

Other questions remained unanswered by this experiment. For example, because no initial testing for moisture content or other characteristics was done on the wood of the vessel, it was not possible to assess the effect of the fibreglassing.

It is recommended, therefore, that another similar project be undertaken, but this time making sure that sufficient preliminary testing is done to enable reliable 'before and after' comparisons of various critical aspects to be made.

Most particularly, vessel draft marks should be recorded, an inclining experiment performed and wood samples removed and thoroughly analyzed before fibreglassing.

In fibreglassing, several procedures in particular should be followed with care. All wood to be covered with fibreglass should be coated with a suitable toxic wood preservative that is not incompatible with the polyester resin which follows. Polyester resins are not to be considered structural adhesives, particularly when applied to wood. Because of this, no permanent bond between the glass and the vessel exists, eventually leading to voids or pockets where the GRP skin is in loose contact with the wood. In these voids, what is not water is air. Both are required for rot to grow - the underlying wood provides the food. Application of a suitable preservative will help prevent this.

All damaged or rotten wood should be replaced with new material prior to glassing.

Care should be taken to apply the recommended number of fibreglass plys to provide adequate strength and resistance against impact and abrasion. This information might be provided by reputable fibreglass boatbuilders or by classification standards such as Lloyds Provisional Rules for Building and Classifying GRP vessels. (It should be noted that these specify the minimum number of plys of alternating mat/roving for the body of the laminate, but do not mention inner and outer plys of mat such as were applied to the M/V WAVE). These must be applied as well, but mainly for waterproofing and bonding purposes.

The fibreglass should be fastened to the hull with highly corrosion resistant screws or annular ringed nails, or other fastenings deemed to be acceptable (eg. galvanized staples or felt nails) after about half the scheduled plys of fibreglass have been applied. Holes for screw or nail fastenings must be pre-drilled and screw heads countersunk for a flush fit. The fastenings should be long enough to penetrate at least two-thirds of the thickness of the plank. The main purpose of the mechanical fastenings is the prevention of flapping against the hull and loss of structural unity.

Where the layup ends on a vertical surface, its edge should be made water proof. This may be done by fastening over the exposed edge a strake set in a suitable marine bedding compound. This would prevent or at least minimize the entry of water underneath the laminate and is easily serviced.

Apply the minimum number of plys to provide sufficient strength and resistance to impact and abrasion. This information can be provided by reputable fibreglass boat builders or a guide such as Lloyds Rules. A safe minimum number of plys of alternating mat/roving to include in the body of the laminate (does not include inner and outer double layers of mat) found in the following table.

Exerpt - LLOYDS PROVISIONAL RULES FOR BUILDING GRP VESSELS.

Hull Length	Mass of Glass Required in Hull	#Plys (450g Mat + 815g Roving = 1265g/m ²)
(33') 10.0 m	4050 g/m ²	3 plys mat/roving
(50') 15.0 m	4800 g/m ²	4 plys mat/roving
(65') 20.0 m	5500 g/m ²	5 plys mat/roving

The hull should be closely fastened after application of approximately one-half the scheduled plys of reinforcing material.

The skin should be reinforced with extra layers in areas subject to high impact loads or abrasion (hatch coamings, hull sides in way of haulers, bulwark rails, etc.) to prevent excessive damage and destruction of the protective fibreglass. Coamings subject to excessive impact damage should be capped with suitable angle iron (or the like), through-bolted and

set into a high quality marine bedding compound (such as 3M-5200) to prevent water from entering around the bolts. Extra plies of glass could be applied to high wear areas such as the hull side or stem ramps.

For ice protection, during the layup, a belt of Kevlar cloth could be applied to the waterline area as the last layer before the finish gel coat. In the case of solid or planked-up bulwarks, why not remove them altogether before proceeding and install a new rail afterwards?

MAINTENANCE

Fibreglass is a relatively inert and maintenance-free material in the normal marine environment. Its comparatively high strength, light weight, resistance to attack by most substances and vermin, and great tolerance to abuse, make it ideally suited for the construction of certain commercial marine craft, particularly fishing vessels.

It is imperative that any local damage which exposes the reinforcing fabrics be repaired immediately. Polyester resins are not totally waterproof, and water can easily penetrate throughout a laminate along exposed glass fibres.

The action of freezing and thawing will cause any water underneath or within a laminate to expand, resulting in localized delamination. This creates a larger space which can be filled with even more water and eventually (after further cycles of freezing/thawing, etc.) the damage is no longer confined but has propagated through a considerably larger area that can be determined visually. The hull should be checked periodically for minor scratches or cracks in the finish. These should be touched up immediately.

Neglected minor damage can grow and eventually require the removal of a large section of fibreglass to effect a proper repair, resulting in much greater costs than if it had been tended to promptly.

Any exposed edges where the fibreglass has been run out (such as up the bulwark, wheelhouse side, or edge of deck etc.) should be checked periodically for separation from the wood. If there is separation, the edge should be covered with a plank set generously in bedding compound and pulled in tightly with suitable screws or bolts.

Indeed it would be wise to treat these exposed edges properly during or immediately after fibreglassing rather than waiting for separation to occur.

Finally, proper ventilation should be considered. Most large wooden boats tend to be closed up too tightly with no systematic approach to ventilating the enclosed spaces behind ceilings, panelling, in forepeaks and especially in the lazarettes. In the case of the **M/V WAVE**, even the bulwark is closed up with wood panels on each side of the stanchions. This provides an excellent, stagnant environment for rot to take hold..

Any enclosed spaces or compartments should be provided with generous venting both near the deck beams and as low into the bilge as possible with some means provided for air escape (i.e. open hatch). The careful positioning of ventilators such as turbines, or even scoops, will provide assistance in generating positive air flow either when the vessel is tied up or in motion.

If the fibreglassing is carefully done there will be less chance of breakage, separation from the wood, or other problems occurring once the vessel is put to work. As tough and durable as fibreglass is, however, such problems will arise, and proper maintenance must be carried out to ensure the long-term viability of the fibreglass sheathing.

The best qualities of fibreglass lend it to much neglect and abuse. With relatively minor care and attention its lifetime can be long and inexpensive.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Fisheries Development Division for requesting that I conduct this study, and, Fisheries Assistance Division for providing leave from regular duties in which to complete it.

I thank especially Mr. Paul Pinhorn for his valuable assistance in the collection and processing of field data and Mr. George Roach for his kind tolerance and help throughout.

I also thank the numerous other individuals and institutions for their willing assistance and information. In particular, The Newfoundland Department of Fisheries, especially the staff at the Harbour Grace Marine Service Center; Neldo Marine Development Co. Ltd., Argentia, Newfoundland; Forintek Canada Corp., Ottawa; The Department of Naval Architecture, Newfoundland Marine Institute, St. John's; C & F Marine Boats Ltd., Lower Wedgeport, N.S.; The Nova Scotia Provincial Department of Fisheries.

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TABLE 1. DETERMINATION OF GLASS CONTENT (PERCENT BY WEIGHT)

ITEM	MASS (BEFORE)	MASS (RESIDUE)	% GLASS
Plug #1	17.800 g.	8.110 g.	45.56
Plug #2	16.240 g.	7.310 g.	45.01

TABLE 2. CALCULATION OF INITIAL GM AND KG FROM INCLINING EXPERIMENT

SHIFT #	MASS MOVED	DISTANCE MOVED	PENDULUM DEFLECTION
1	0.244 t	3.20 m	0.10 m
2	0.241 t	3.08 m	0.11 m
3	0.234 t	3.58 m	0.12 m
4	0.244 t	3.25 m	0.11 m
5	0.244 t	3.03 m	0.10 m
6	0.241 t	2.97 m	0.10 m
7	0.234 t	3.44 m	0.10 m
8	0.244 t	3.30 m	0.11 m
AVERAGE	0.241 t	3.238 m	0.1063 m

$$GM = \frac{wdl}{a}$$

$w = \text{average mass moved (tonnes)}$
 $d = \text{average distance moved (metres)}$
 $l = 6.337 \text{ m (pendulum length in metres)}$
 $a = \text{average deflection (metres)}$
 $= \text{vessel displacement (47.183 tonnes)}$

$$GM = \frac{4.9451286}{5.0155529}$$

$$GM = 0.986 \text{ m}$$

CENTER OF GRAVITY

Since KM, from the hydrostatics (Figure 6), was found to be 3.404m and KG = KM - GM (KG = 3.404 - 0.986) KG (center of gravity) = 2.418m above the baseline.

NOTE: The baseline used for hydrostatics and stability calculations was the keel bottom, at midships.

TABLE 3. CALCULATION OF GZ (RIGHTING LEVER)

ANGLE OF KEEL	KN(m)	KG(sin ϕ)	GZ=KN-KG(sin ϕ)
0°	0.800	0	0
10°	0.600	0.420	0.180
20°	1.122	0.827	0.295
30°	1.487	1.209	0.278
40°	1.805	1.554	0.251
50°	1.988	1.852	0.136
60°	2.118	2.094	0.024
70°	2.129	2.272	-0.143
80°	2.124	2.381	-0.257
90°	1.984	2.418	-0.434

AREAS UNDER GZ CURVE (Figure 4)	COAST GUARD REQUIREMENTS (MINIMUM)
(A) 0° - 30° = 0.111 m radians (B) 0° - 40° = 0.155 m radians (C) 30° - 40° = 0.044 m radians	(A) 0.055 meter radians (B) 0.090 meter radians (C) 0.030 meter radians
(A) Minimum GZ @ 30° = 0.278 (B) Maximum GZ occurs @ 20° list (C) Initial GM = 0.986 m	(A) 0.200 meter radians (B) Must occur greater than 25° list (C) Must be 0.35 m or greater

TABLE 4. ADDITION OF 2.50 t BALLAST

CALCULATE NEW KG (VERTICAL CENTER OF GRAVITY)			
ITEM	MASS (t)	KG(m)	V.MOMENT(tm)
Hull	47.183	2.418	114.09
Ballast	2.50	-2.000	-5.00
	49.683		109.09

2.50 t added; 2.00 m below KG (Center of Gravity), or 42m above bottom of keel at midships.

New kg = moments ÷ mass

$$= \frac{109.09 \text{ tm}}{49.683 \text{ t}}$$

$$= 2.196 \text{ m}$$

GM = KM - KG

$$= 3.464 - 2.196$$

$$= 1.268 \text{ m}$$

VALUES FOR NEW GZ CURVE

CALCULATE NEW VALUES OF GZ (BALLASTED CONDITION)				
ANGLE OF LIST	KN	KG (SIN ϕ)	NEW GZ	AREAS UNDER NEW GZ CURVE
0	0	0	0	
10	0.60	0.381	0.219	(1) Area 0°-30°
20	1.118	0.751	0.367	= 0.140 m rads
30	1.485	1.098	0.387	
40	1.791	1.412	0.379	(2) Area 0°-40°
50	1.968	1.682	0.286	= 0.203 m rads
60	2.088	1.902	0.186	
70	2.118	2.064	0.054	(3) Area 30°-40°
80	2.094	2.163	-0.069	= 0.063 m rads
90	1.971	2.196	-0.225	

- NB: 1. Range of stability increased from 62.10° to 74.29°.
 2. Maximum GZ occurs @ 30° list. This satisfies Canadian Coast Guard.

TABLE 5. NET EFFECT OF GRP/SCREWS ON CENTER OF GRAVITY

ITEM	MASS (t)	KG(m)	V.MOMENT(tm)
Hull c/w all GRP	47.133	2.418	114.083
Hull Bottom (GRP only)	-0.566*	0.945	-0.535
Hull Sides (GRP only)	-0.878*	2.356	-2.069
Deck (GRP only)	-0.598*	3.082	-1.843
Wheelhouse (GRP only)	-0.092*	4.005	-0.369
Net Mass = 45.049 t		Net Moment = 109.272	

*-Negative indicates removing this weight from the hull.

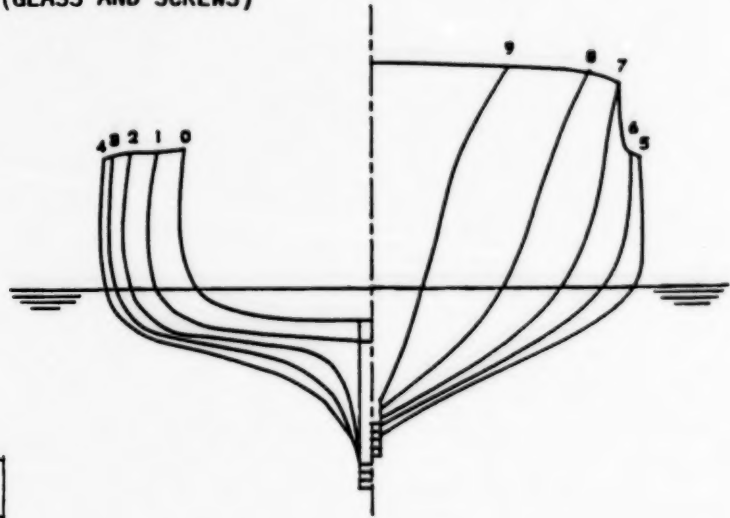
$$\begin{aligned}
 \text{*Approximate KG before fibreglassing} &= \frac{\text{Moments}}{\text{Mass}} \\
 &= 2.426 \text{ m}
 \end{aligned}$$

Net effect on KG due to GRP:

$$\begin{aligned}
 \text{KG after fibreglass} &= 2.418 \text{ m} \\
 \text{KG before fibreglass} &= 2.426 \text{ m} \\
 &\quad -0.008 \text{ m}
 \end{aligned}$$

*Indicates an improvement in stability because KG was lowered by 8 mm after fibreglassing.

FIGURE 1. DECK AREA AND MASS (GLASS AND SCREWS)



STN	BEAM (m)	S/M	f(A)
0	1.765	1	1.762
1	2.045	4	8.180
2	2.300	2	4.600
3	2.478	4	9.912
4	2.558	2	5.116
5	2.601	4	10.404
6	2.516	2	5.032
7	2.394	4	9.576
8	2.106	2	4.212
9	1.319	4	5.276
10	0.000	1	0.000
			= 64.070

$$\begin{aligned}
 \text{Area} &= \frac{2h}{3} f(A) \\
 &= \frac{2(1.844)}{3} (64.070) \\
 &= 78.763 \text{ m}^2 \\
 &= 847.777 \text{ ft.}^2
 \end{aligned}$$

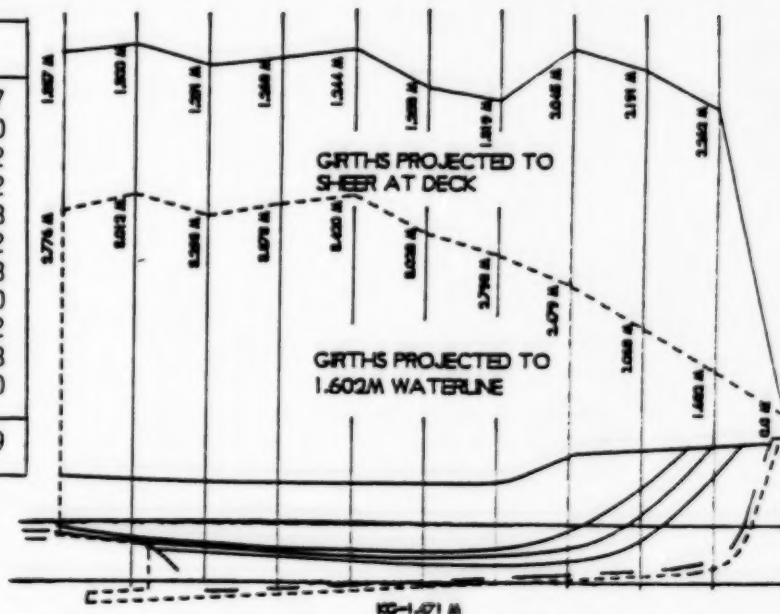
$$\begin{aligned}
 \text{Approximate area covered by house} \\
 &= 256 \text{ ft.}^2 \\
 &= 23.784 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{*Net Deck Area} &= 54.979 \text{ m}^2 \\
 &= 591.777 \text{ ft.}^2
 \end{aligned}$$

- Mass of GRP on Deck:
 $= (591.777 \text{ ft.}^2) (2.16 \text{ lb./ft.}^2)$
 $= 1278.238 \text{ lb.}$
 $= 0.5797 \text{ tonne}$
- Number of Screws:
 $= \frac{(85215.888 \text{ m}^2)}{64 \text{ in.}^2/4}$
 $= 5326$
- Mass of Screws:
 $= (5326)(0.0075770916)$
 $= 40.356 \text{ lb.}$
 $= 18.30 \text{ kg}$

FIGURE 3. HULL SIDE AREA AND MASS (FROM 1.602 M W/L TO THE DECK AT THE HULL SIDE) (GRP + SCREWS)

STN	GIRTH (m)	S/M	f(A)
0	1.357	1	1.357
1	1.300	4	5.200
2	1.291	2	2.582
3	1.263	4	5.052
4	1.244	2	2.488
5	1.253	4	5.012
6	1.319	2	2.638
7	2.045	4	8.180
8	2.191	2	4.382
9	2.262	4	9.048
10	0.000	1	0.000
			= 45.939
h = 1.844 m			



$$\begin{aligned}
 1. \text{ Area} &= \frac{2h}{3} f(A) \\
 &= \frac{2(1.844)(45.939)}{3} \\
 &= 56.474 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 2. \text{ Area Transom (ABOVE W/L)} \\
 &= 4.524 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 3. \text{ Total Hull Area Above} \\
 \text{(Above W/L)} \\
 &= 61.0 \text{ m}^2 \\
 &= 656.583 \text{ ft.}^2 \\
 &= 94,547.88 \text{ in.}^2
 \end{aligned}$$

*Screws were approximately 0.00344 kg each
 **GRP skin was found to be 14.04 kg/m² (2.88 lb./ft²)

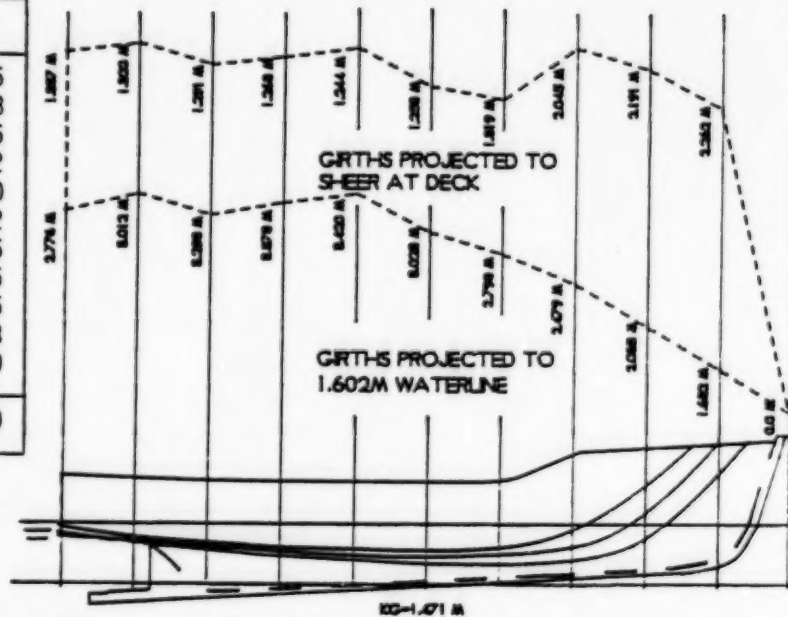
$$(A) \# \text{ Screws} = \frac{94,547.88 \text{ in.}^2}{64 \text{ in.}^2/4 \text{ screws}} = 5909$$

$$\begin{aligned}
 (B) \text{ Mass of Screws} &= (5909)(0.00344 \text{ kg}) \\
 &= 20.33 \text{ kg (44.82 lb.)}
 \end{aligned}$$

$$\begin{aligned}
 (C) \text{ Mass of GRP} &= (\text{Area})(\text{Mass/Unit}) \\
 &= 656.583 \text{ ft.}^2 (2.88 \text{ lb./ft.}^2) \\
 &= 1890.959 \text{ lb.} \\
 &= 0.858 \text{ tonne}
 \end{aligned}$$

FIGURE 2. UNDERWATER AREA AND MASS UP TO 1.602m W/L (GLASS AND SCREWS)

STN	GIRTH (m)	S/M	f(A)
0	2.776	1	2.776
1	3.012	4	12.048
2	3.298	2	6.596
3	3.373	4	13.492
4	3.420	2	6.840
5	3.023	4	12.092
6	2.798	2	5.596
7	2.479	4	9.916
8	2.088	2	4.176
9	1.682	4	6.728
10	0.000	1	0.000
			= 80.260



NOTE: ALL MEASUREMENTS WERE TAKEN FROM LINES PLAN OF VESSEL.

1. Underwater Hull Area

$$= \frac{2(1.844)(80.260)}{3}$$

$$= 98.666 \text{ m}^2$$

$$= 1062.006 \text{ ft.}^2$$

$$= 152,928.86 \text{ in.}^2$$

2. Underwater Portion of Transom Area

$$= 0.720 \text{ m}^2$$

$$= 3.875 \text{ ft.}^2$$

$$= 558.0 \text{ in.}^2$$

3. Total Underwater Area of Hull

$$= \text{Hull} + \text{Transom}$$

$$= 99.386 \text{ m}^2$$

$$= 1065.881 \text{ ft.}^2$$

$$= 153486.86 \text{ in.}^2$$

(A) Each 64 in.² contains 4 screws
each screw weighs 3.44 g (0.0075770916 lb.)
1) # screws = $\frac{153486.86 \text{ in.}^2}{64 \text{ in.}^2 / 4 \text{ screws}} = 9593$

2) Mass of screws = 72.687 lb.
32.965 kg.

(B) Mass of GRP added
Mass = $(1065.88 \text{ ft.}^2)(2.88 \text{ lb. ft.}^2)$
= 3069.74 lb. (1.392 m. tonnes)

(C) Effective Mass of GRP (when afloat)

Due to ratio of densities

$$\frac{1.025}{1.66} = \frac{\text{Seawater}}{\text{GRP}}$$

38.25% of total glass affects displacement, the rest is supported by surrounding water

Effective Additional
Mass = $(3069.74)(0.3825)$
= 1174.176 lb.)

GLOSSARY

1. **RESIN** - General purpose polyester resins used in the construction of fibreglass items. Contains styrene monomer to provide crosslinking and high strength chemical bonding.
2. **LOW EXOTHERM RESIN** - Resin which produces low heat during cure resulting in longer gel times.
3. **HIGH EXOTHERM RESIN** - High heat producing resin which gels much faster.
4. **CATALYST** - One of several chemical compounds which when added to resin containing a compatible accelerator produces heat which causes the resin to harden. Varying amounts will increase/decrease gel times.
5. **M.E.K.** - Methyl Ethyl Keytone peroxide - a catalyst.
6. **PRIMARY BOND** - A high strength chemical bond achieved by crosslinking polyester molecules with styrene. The strongest bond achievable with polyester resin.
7. **SECONDARY BOND** - A lower strength bond achieved by grinding fibreglass until the glass strands break and stick up from the surface. Fresh resin applied to this surface, when it cures, locks itself around these fragments forming a mechanical bond. Occurs when too much time has elapsed before applying fresh resin to previous layup, styrene is lost from the surface and no chemical crosslinking can occur.
8. **STYRENE** - A reactive diluent monomer added to polyester resins. Important for formation of short chain primary bonds which are more flexible than "end chain" polyester polymer bonds.
9. **G.R.P./F.R.P.** - Abbreviations for fibreglass (Glass Reinforced Plastic/Fibreglass Reinforced Plastic).
10. **ROVING** - A plain, square weave reinforcing material consisting of flattened bundles or rovings of fibreglass filaments 1/8" to 1/4" wide and ranging in weight from 14 to 27 oz./yd.
11. **MAT** - A reinforcing material consisting of either continuous or chopped strands of fibreglass randomly deposited and held together with a high solubility resin binder and formed into a sheet.
12. **BURNOUT** - A destructive test performed by burning out all resin in a G.R.P. sample. Used to calculate "glass fibre" content and determine quality of layup.

13. **LAMINATE** - General term used to describe the construction or layup of fibreglass.
14. **RESIN RICH** - Very low glass content (% by weight). Indicates a poor quality laminate. Caused by poor technique, wrong resin, or excessive gel time (undercatalyzation). Too much resin.
15. **RESIN STARVED** - Very high glass content and poor interlaminar bonding. Indicates a poor quality laminate. Not enough resin. Causes are various.
16. **M.C.** - Moisture content (in this case, of wood). Can be expressed in terms of percent by weight or volume.
17. **KM** - Distance from keel (at baseline on lines plan) to a point called the Metacenter (M). The force of buoyancy acts vertically along a line passing through M when a vessel is listed (heeled over).
18. **KB** - Vertical distance from the keel at midships (or baseline used for hydrostatic calculations) to the center of buoyancy (B) of vessel.
19. **KG** - Vertical distance from the keel at midships (or hydrostatic baseline) to the center of buoyancy (G) of vessel.
20. **GM** - Distance from the center of gravity to the metacenter. This is calculated from the results of an inclining experiment.
21. **KN** - The horizontal measurement of the "shift" of Center of Buoyancy resulting from a vessel being listed (heeled over).
22. **GZ** - The horizontal distance between Center of Gravity (KG) and Center of Buoyancy (KB) during a condition of heel. Referred to as the "Righting Lever" and is used to determine the ability of a vessel to return upright when pushed over by an external force.